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Evaluation of CO_2 storage potential, injectivity and uncertainly by the numerical analysis on feasibility study sites

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Abstract

This paper describes our evaluation of CO_2 storage potential, injectivity and uncertainly, with a focus on CO_2 sealing efficiency, through numerical analysis using TOUGH2/ECO2N applied to a feasibility study site (which we call "Site D").

In the first step, we examined previous geological survey data and a geological model created to predict feasibility of the study sites. Storage potential of selected areas, the number of required injection wells and their arrangement, and CO_2 migration in the proposed site were examined through simulation with TOUGH2/ECO2N [1].

Secondly, to create a conceptual model, we simplified the geological situations at the injection point and carried out a sensitivity analysis for understanding the uncertainty. The sensitivity analysis revealed that permeability, capillary pressure, layer thickness, and modeling of the alternating layers will greatly affect our results. Through this numerical analysis focused on sealing efficiency, we estimate the maximum amount of injectable CO_2 in Site D at 1 million tons per well.

Keywords: CO2 storage potential, injectivity, uncertainly, numerical analysis, feasibility study

1. Introduction

In feasibility study of CO_2 geological storage, evaluation of the quantity which can be confined in the storage layer over a long term on the examination site are important items. At this feasibility study stage,

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when sufficient geological survey data have not yet been gathered, it is also important to understand the uncertainty inherent in the numerical-analysis results.

We collected previous geological survey data and the geological model created in feasibility study sites. And storage potential in selected area, the number of required injection wells, arrangement of injection wells, and CO_2 migration in the proposed site were examined by the simulation using TOUGH2/ECO2N.

In the feasibility study stage, since sufficient geological survey data is not obtained, it is also important to understand the uncertainty of the numerical-analysis results.

Here, we explained the CO_2 storage potential, injectivity and uncertainly focused on CO_2 sealing efficiency and the relation the degree of uncertainty in rock properties and the simulation results for Site D.

2. Geology and General Simulation Study of Site D

2.1. Geology

Geological situation for Site D were shown in Fig 1. This sedimentary basin, with a thickness of 4,000 m, mainly consists of sediments from the Neocene to Paleocene periods. A vast amount of previous geological survey information is available for this basin. Four holes were drilled during a refraction seismic survey conducted through 124 survey lines with a total length of 4,162 m.

The sandstone layer selected as a reservoir has a thickness of approximately 200–300 m and is situated at a depth of 800–2,500 m.

In order to select areas with a low leakage risks in the site D, the geological structures and faults were interpreted in detail and 4 areas where a fault does not exist closely were selected (Fig 2). The total of the CO_2 storage capacities of these 4 areas were estimated as 370 million ton CO_2.

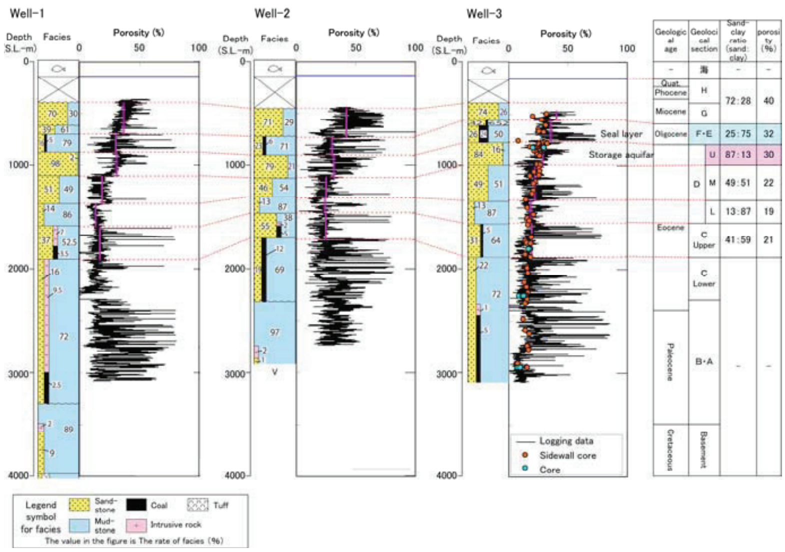
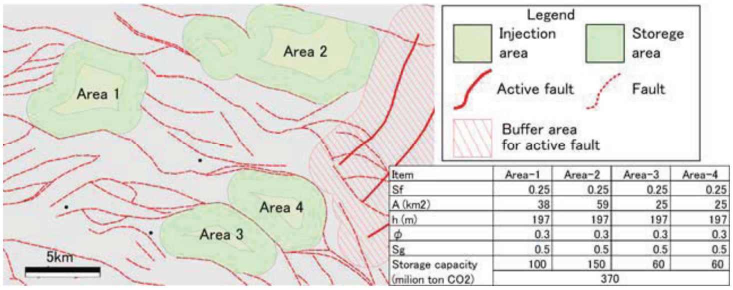


Fig. 1. Geological situation for Site D



Item	Area-1	Area-2	Area-3	Area-4
Sf	0.25	0.25	0.25	0.25
A (km2)	38	59	25	25
h (m)	197	197	197	197
ϕ	0.3	0.3	0.3	0.3
Sg	0.5	0.5	0.5	0.5
Storage capacity (milion ton CO2)	100	150	60	60
	370			

Fig. 2. The 4 areas where a fault does not exist close and storage capacities of the 4 areas in Site D

2.2. Numerical simulation study of commercial use and large-scale storage for Site D

The injection rate, number of injection wells, long-term migration of the injected CO_2, and positions of injection wells were examined via numerical simulations using detailed geological 3D models created on the basis of various pieces of information such as oilfield survey data.

Considering various specifications and layouts of the injection wells, the criteria listed in Table 1 were used for the storage design concept. In this study, injection via vertical injection wells was assumed because it is considered more economical than that via horizontal injection wells. For conditions in which injection by using a single vertical injection well was judged to be difficult, a horizontal injection well with a larger CO_2 injection capacity was employed.

Rock properties used for the numerical model, the number of the injection wells defined on the basis of the numerical analysis results, and the spreading parameters of supercritical CO_2 are summarized in Table 2. Figure 3, 4 and 5 show examples of the numerical analysis results for Site D.

Table 1. Conditions considered for examination of storage design concept

Parameter	Description
Assumed storage capacity	- Commercial use: 1,540,000 t - CO_2 × 20 years - Large-scale storage: 10,000,000 t - CO_2 × 20 years
Injection conditions	- The maximum injection pressure shall not exceed the fracture pressure. - CO_2 injection shall be conducted at a pressure equal to or less than the specified maximum pressure at a constant flow rate. - For commercial use, operation at 80% of the entire system capacity shall be assumed.
Storage conditions	- Basically, the injected supercritical CO_2 shall be retained in the specified storage area. - When multiple promising storage candidates exist at the same point, the uppermost storage shall be prioritized for economic reasons. - Supercritical CO_2 shall not reach a large-scale fault.
Injection well conditions	- The type of injection well shall be vertical or horizontal. - The maximum horizontal length of a horizontal injection well shall be determined after consideration of comments from the wellbore drilling company.

Table 2. Summary of rock properties and numerical results

Object	Item	unit	Site D	
	water depth	m	120–150	
reservoir	typical depth	m	1300–1800	
	thickness	m	200–400	
	porosity	%	30	
	permeability (Kh)	md	33	
	Swir,Sgc,Sgr		0.58,0.05,0.29	
seal aquifer	permeability (Kv)	md	1.3	
	entry pressure	kPa	0.12	
Numerical anarysis			commercial	large-scale
	the number of injection well	well	2	10
	storage area	km2	20	60

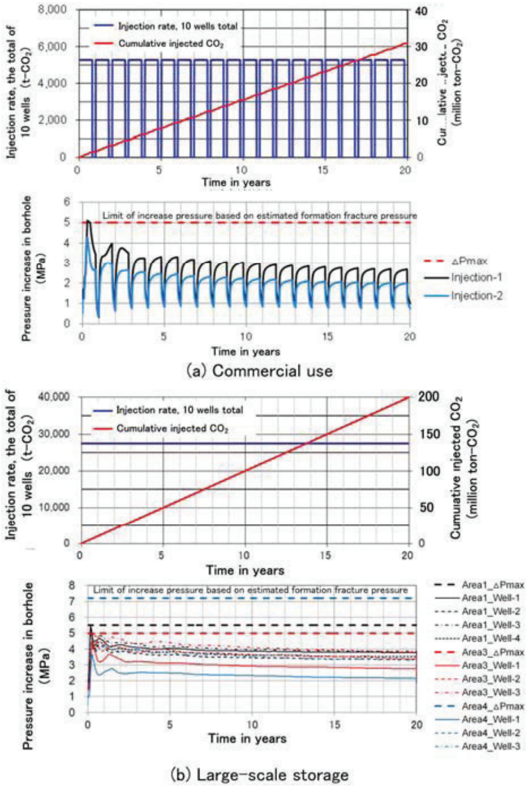


Fig. 3. Numerical results for injectivity.

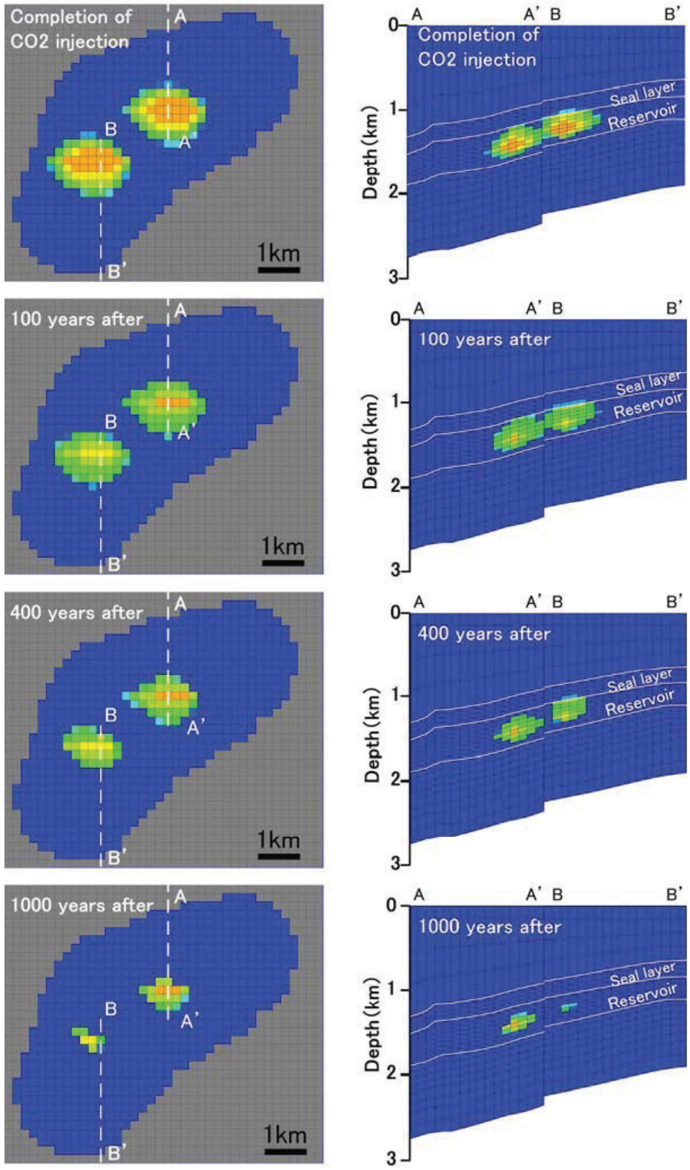


Fig. 4. The spread of the CO_2 plume in the case of Commercial use

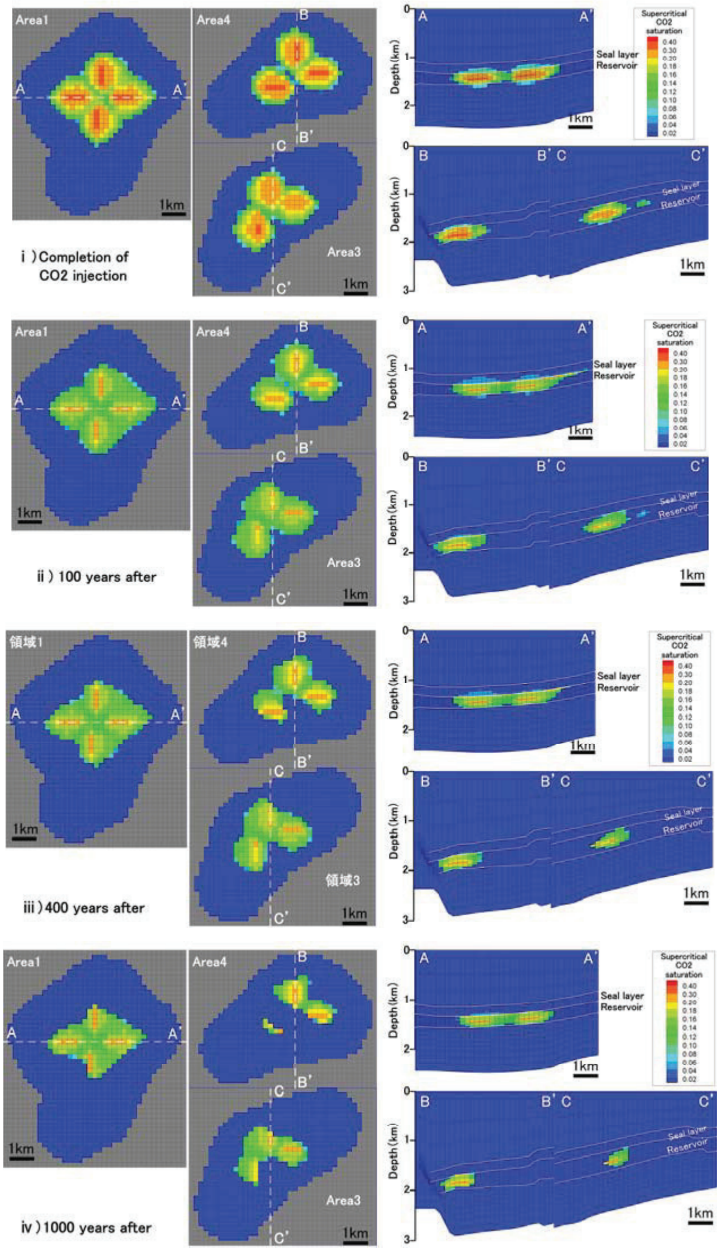


Fig. 5. The spread of the CO_2 plume in the case of large scale CO_2 storage

3. Results of Sensitivity Analysis

A simplified axisymmetric model was created to represent the geological situation at the selected area. Figure 6 shows a schematic of the model geometry and the numerical axisymmetric model. Table 3 shows the properties of the reservoir and seal layer as a standard case. The radius of the model has sufficient length (100 km) to avoid the effect of a side boundary condition on CO_2 migration behavior.

In order to evaluate the quantity which can be confined in the storage layer over a long term, the sensitivity analysis focus attention on the parameters of seal layer was carried out.

Variable parameters were fineness of the modeling of alternation, permeability, porosity, irreducible water saturation, capillary pressure. The ranges of parameters for sensitivity analysis, the maximum and the minimum value, were estimated on literatures value.

Table 3 shows the properties of standard case and variable parameters of seal layer.

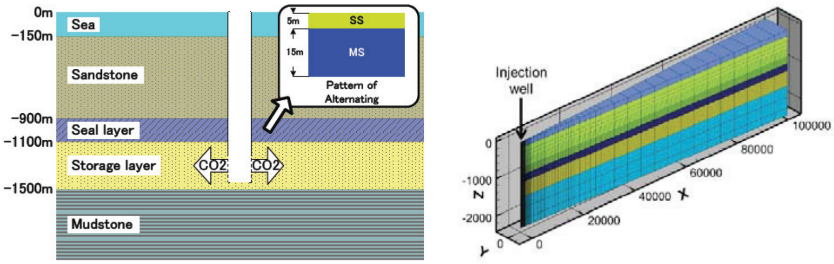


Fig. 6. The schematic of the model geometry and the numerical axisymmetric model

Table 3. The properties of the reservoir and seal layer as a standard case (left)

and variable parameters of the seal layer (right)

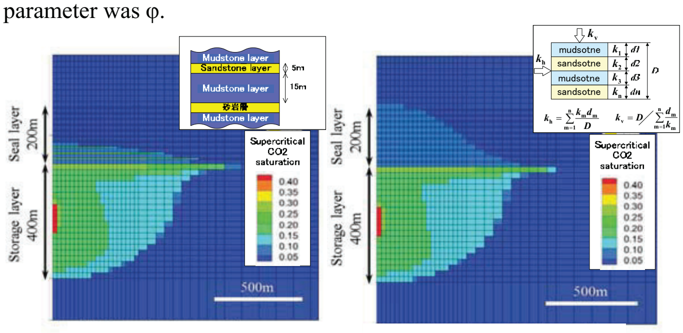
Property	Seal layer		Strage layer
	MS	SS	
Porosity (%)	32	32	30
Permeability (vertical)	0.8	36	3.1
Permeability (horizontal)	0.8	36	18
Relative Permeability			
function	VG[1)]	VG[1)]	VG[1)]
λ	0.4	0.4	0.4
Slr	0.8	0.54	0.6
Sls	0.95	0.95	0.95
Sgr	0.05	0.05	0.05
Capillary Pressure			
function	VG[2)]	-	-
λ	0.4	-	-
Slr	0.8	-	-
P_0(Pa)	$3x10^5$	-	-
P_{max}(Pa)	$1x10^6$	-	-
Sls	1	-	-

1) Liquid:van Genuchten(1980) ; Gas:Corey(1954)
2) van Genuchten(1980)

Item	Standard model	Value of a variable	Case
Modeling	Alternation model	Alternation model	Case1-1
		Equivalent permeability model	Case1-2
Injection rate	1 milion ton-CO2/year	1.5 milion ton-CO2/year	Case2-1
		0.5 milion ton-CO2/year	Case2-2
Permeability	0.8 md	4 md	Case3-1
		0.08 md	Case3-2
Porosity	32%	44%	Case4-1
		20%	Case4-2
Capillary pressure	$P_0 = 300$ kPa	$P_0 = 600$ kPa	Case5-1
		$P_0 = 30$ kPa	Case5-2
	λ = 0.4	λ = 0.8	Case6-1
		λ = 0.2	Case6-2
Irreducible water saturation	Swir = 0.8	Swir = 0.9	Case7-1
		Swir = 0.7	Case7-2
Permeability and Capillary pressure	K = 0.8 md $P_0 = 300$ kPa	K=4 md, P_0=200kPa	Case8-1
		K=0.08md, P_0=510kPa	Case8-2

Figure 7 shows numerical results on the model expressing alternation of mudstone and sandstone and the model of equivalent coefficient of permeability. In the case of alternation model, CO_2 migration front was the 4th alternate layer, 80m upper from the bottom of seal layer. In the case of equivalent permeability model, CO_2 migration front exceeded at top of seal layer slightly. This shows that diffusion of CO2 pressure the parts of sandstone in the seal layer influences CO_2 migration.

Table 7 shows the results of sensitivity analysis using alternation model. The differences in the CO_2 migration by change of parameters were 40 to 60 m in many cases. The parameters with high sensitivity of CO_2 migration in seal layer were Capillary pressure (p0, λ)[2] and injection rate. Low sensitivity parameter was φ.



(a) Alternating layer model

(b) Equivalent permeability model

Item	Case	CO2 Front Position[1)] (m)	Difference (m)	Sensitivity
Modeling	Case1-1	80	>120	High
	Case1-2	>200		
Injection rate	Case2-1	100	60	Medium
	Case2-2	40		
Permeability	Case3-1	80	40	Low
	Case3-2	40		
Porosity	Case4-1	80	0	very Low
	Case4-2	80		
Capillary pressure	Case5-1	40	>160	High
	Case5-2	>200		
	Case6-1	100	60	Medium
	Case6-2	40		
Irreducible water saturation	Case7-1	40	40	Low
	Case7-2	80		
Permeability and Capillary pressure	Case8-1	80	40	Low
	Case8-2	40		

1) From bottom of seal layer

(c) Equivalent the results of sensitivity analysis

Fig.7. The schematic of the model geometry, the numerical axisymmetric model and the results of sensitivity analysis

From the result of a sensitivity analysis, even if it takes the degree of uncertainty in rock properties into consideration, it is thought that the injection rate of 1 million t-CO_2 is possible. However, sufficient investigation is required for the situation of alternation and the characteristic of the capillary pressure in seal layer.

In this project at site D, two types of injection amount were considered. These are as follows;

・Commercial project level is 31 million tons-CO_2 in total (1.54 million ton-CO_2 per year, 20 years injection cycle)

・Large-scale CO_2 storage is assumed to be 200 million tons in total (10 million ton-CO_2 per year, 20 years injection cycle).

The number of required injection well is 2 for commercial project level and large-scale CO_2 storage is required 10 injection wells.

Further research, the model which reproduced the geological condition in detail is due to examine.

Acknowledgements

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